Studies on the *Mytilus edulis* Community in Alamitos Bay, California. - IV. Seasonal Variation in Gametes from Different Regions in the Bay

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(5 Text figures; 1 Table)

INTRODUCTION

THE BAY MUSSEL, *Mytilus edulis* LINNAEUS, 1758, is distributed throughout Alamitos Bay, California (Figure 1). It is especially abundant wherever floating boat docks occur, but in the upper reaches of the bay, notably Colorado Lagoon and Cerritos Channel, the number of specimens decreases. The chlorinity of the bay is uniform throughout except immediately following infrequent winter rains (STONE & REISH, 1965). Since formation of the gametes and subsequent fertilization and development is essentially for repopulation, and since *M. edulis* is distributed throughout the bay, the authors were curious whether or not the mussels will produce gametes in all areas of their distribution in the bay, and, if so, would they be produced at the same or at different times of the year. In other words, is the reproductive population in a limited area of the bay surrounded by a vegetative, non-reproductive population of *M. edulis?* Gonadal tissue was examined periodically from 4 areas of the bay to determine whether or not seasonal differences occurred within an area and from area to area.

The seasonal reproduction of *Mytilus edulis* has been studied in the past by the analysis of gonads (FIELD, 1922), CHIPPERFIELD (1953), SUGIURA (1959), and by seasonal attachment of larvae by ENGLE & LOOSANOFF (1944), GRAHAM & GAY (1945), CHIPPERFIELD (1953), and LOOSANOFF & DAVIS (1963), and REISH (1964a). CHIPPERFIELD indicated sexually mature mussels occurred from mid-April to the end of May in British waters. Gamete maturation began when the water temperatures reached 7° C and spawning commenced while the temperatures were rising from $9\frac{1}{2}$° to $12\frac{1}{2}$° C. In warmer Japanese waters, SUGIURA (1959) noted gamete maturation occurred when the water temperature dropped to 18° C in the fall. Larval settlement took place in late spring and early summer in Connecticut (ENGLE & LOOSANOFF, 1944), in central California (GRAHAM & GAY, 1945), and in England (CHIPPENFIELD, 1953). However, in Alamitos Bay larval settlement occurred in late winter and early spring when the water temperatures were not below 13° C (REISH, 1964a).

Since the previous studies on seasonal reproduction in *Mytilus edulis* have been carried out in more northern latitudes, the purpose of this study was to determine whether or not a seasonal variation in the maturity of the ova and sperm occurred in Alamitos Bay. An additional purpose of this study was to investigate whether or not variations in the degree of intensity of reproduction existed in populations from different areas of the bay.

MATERIAL AND METHODS

Monthly samples of *Mytilus edulis* were collected from 4 localities within Alamitos Bay, Long Beach, California, from November, 1964 through July, 1966 (Figure 1). Subsurface water temperatures were taken at the time of collection. Water samples were taken for chlorinity determinations during the first year. Since this value varies only during periods of rainfall (STONE & REISH, 1965), the chlorinity data were not included herein because they were of little significance to this report. Samples were taken from Stations 1 and 2 at the same time and at Stations 3 and 4 one or two weeks later.

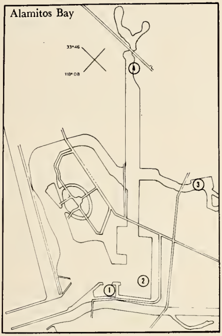

Figure 1

Map of Alamitos Bay, California, showing Station Locations

Stations 1, 3, and 4 represented extremes in the distribution of the population where sufficient numbers of specimens were present. Station 2 is in an intermediate location where earlier studies on *Mytilus edulis* were conducted (REISH, 1964a, 1964b). Occasional specimens occur along the rock jetty at the channel entrance and up the channel from Station 3, but there was not a sufficient number of specimens to permit analysis. All mussels were collected from floating boat docks; thus, the specimens were always covered with water.

The specimens were brought back to the laboratory to ascertain the degree of gamete development. Smears were made of gonadal tissues, and the classification system of CHIPPERFIELD (1953) was followed as:

Stage 0. Sex unknown (indeterminate); no follicles present.

Stage 1. Follicles present; sperm mother cells and spermatids present; a few small oocytes seen.

Stage 2. Sperm present, but not motile; ova not fully developed, wrinkled, and would not become spherical when placed in sea water; no fertilization.

Stage 3. Sperm motile; ova fully developed and became spherical when placed in sea water; fertilization.

Recent spent stage: A few residual gametes left in follicles.

Ten individuals of each sex were selected for microscopic examination of gonadal smears. Mature males could be distinguished by the cream or yellowish-cream colored gonads, and mature females by their apricot or red-brown colored gonads. The colors of the gonads were light orange or light yellow in stages 1 and 2 of both sexes. Gonadal smears were made of each specimen and the stage of development was noted. A separate count of indeterminates or recently spent mussels was made.

An average stage of gamete development was calculated for each male and female each month by totalling the figures for the different stages observed and dividing the number of individuals examined. The number of indeterminates was totalled separately.

DATA

The data for the seasonal variation in male and female gamete development over the 20-month period of observation are presented in Table 1 and Figures 2 to 5. The range and average stage of gametogenesis for each sex are presented by date for the 4 stations in Table 1. The data are summarized graphically by station for each sex for each period of observation as the average stage of gamete development. These averages are based on 10 specimens of each sex except when a large number of indeterminates was encountered. The number of indeterminates and the water temperature are also included in each graph.

The data show that some degree of gametogenesis occurred in both sexes to a greater or lesser extent at all stations throughout the entire period of observation from November 1964 through July 1966. However, the degree of gametogenesis fluctuated seasonally in both males and females. The higher levels of gamete development were observed during the late fall and early winter months.

Mussels with mature gametes decreased in numbers from March to the end of July each year. The greatest number of indeterminates was observed from May to October.

SEASONAL VARIATION IN MALE GAMETOGENESIS

Mature sperm were present in some specimens at all 4 stations throughout the period of observation except at Station 2 in March and April 1965 and at station 4 in July 1966 (Table 1). However, a seasonal variation in the average stage of gamete development occurred at all stations, and, furthermore, variations in the degree of gamete maturity from station to station were noted (Figures 2 to 5).

A total of 68 samples was taken from all stations during the 20 months of study; of these 14 (or 21%) of the samples of males were composed entirely of mussels at stage 3 of gamete development. Six of these 14 samples were observed at Station 1, 3 each at Stations 2 and 3, and 2 at Station 4. Only 3 samples, or 4%, of the 68 samples did not have any individuals at stage 3 of gamete development. The overall average stage of male gamete development was 2.6, 2.5, 2.5, and 2.4 for Stations 1 to 4, respectively. The length of time during which the average gamete stage of development was high (over 2.5) and longer was at Stations 1 and 2.

An inverse relationship between the male gamete stage and water temperature was observed at all stations (Figures 2 to 5). The low point in the average stage of male gamete development occurred from the months of March to August when the water temperature rose from 17° C to 24°C. The high point in the average stage of male gamete development occurred from October to February when the water temperature dropped from 24° to 13° C.

Table 1

Seasonal Changes in the Stages of Gamete Development in Males and Females of *Mytilus edulis* Based on a Numerical Scale of 1 to 3[1]

Date	Station 1				Station 2				Station 3				Station 4			
	Males		Females		Males		Females		Males		Females		Males		Females	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
1964																
November 18, 24	3	3.0	1 - 2	1.9	2 - 3	2.8	1 - 3	1.8	1 - 3	2.3	1 - 2	1.8	2 - 3	2.4	1 - 3	1.8
December 2, 9	3	3.0	1	1.0	2 - 3	2.8	1 - 2	1.1	2 - 3	2.8	1 - 3	1.7	3	3.0	1 - 2	1.1
1965																
January 6, 13	3	3.0	1 - 2	1.2	1 - 3	2.6	1 - 2	1.6	3	3.0	1 - 2	1.3	2 - 3	2.9	1	1.0
February 3, 10	3	3.0	1 - 2	1.0	2 - 3	2.7	1 - 2	1.2	1 - 3	2.8	1 - 3	1.3	2 - 3	2.7	1	1.0
March 3, 17	1 - 3	2.2	1 - 2	1.1	1 - 2	1.5	1 - 2	1.2	1 - 3	2.3	1 - 2	1.5	1 - 3	2.1	1	1.0
April 7, 21	1 - 3	1.6	1	1.0	1 - 2	1.5	1	1.0	1 - 3	2.5	1 - 2	1.3	1 - 3	2.2	1 - 2	1.1
May 5, 12	1 - 3	2.3	1 - 2	1.1	1 - 3	2.5	1	1.0	1 - 3	2.3	1 - 2	1.4	2 - 3	2.4	1	1.0
June 2	1 - 3	2.3	1	1.0									1 - 3	2.1	1 - 2	1.1
July 12, 19	1 - 3	2.4	1 - 2	1.1	1 - 3	2.0	1 - 2	1.2	1 - 3	2.1	1 - 2	1.3	1 - 3	2.2	1 - 2	1.3
August 2, 16	1 - 3	2.0	1 - 2	1.2	1 - 3	2.3	1 - 2	1.6					1 - 3	2.1	1 - 2	1.1
September 9, 15	1 - 3	2.3	1 - 2	1.5	2 - 3	2.9	1 - 2	1.3	1 - 3	2.3	1 - 2	1.5	1 - 3	2.3	1 - 3	1.2
October 6, 13	3	3.0	1 - 2	1.3	3	3.0	1 - 2	1.2	3	3.0	1 - 2	1.4	2 - 3	2.6	1 - 2	1.4
November 10	2 - 3	2.9	1 - 2	1.3	2 - 3	2.9	1 - 2	1.4					3	3.0	1 - 2	1.5
December 1, 8	3	3.0	1 - 2	1.3	2 - 3	2.9	1 - 2	1.4	2 - 3	2.9	1 - 3	1.9	2 - 3	2.8	1 - 2	1.1
1966																
February 2	2 - 3	2.9	1 - 3	1.8	2 - 3	2.9	2 - 3	2.4	3	3.0	1 - 3	1.8	1 - 3	2.1	1 - 2	1.2
March 17, 22	2 - 3	2.8	1 - 2	1.1	3	3.0	1 - 3	1.6	2 - 3	2.9	1 - 3	1.6	2 - 3	2.7	1 - 2	1.2
May 3, 31	1 - 3	2.6	1 - 2	1.1	3	3.0	1 - 2	1.3	1 - 3	2.0	1 - 3	2.3	1 - 3	2.6	1	1.0
July 12	1 - 3	1.8	1	1.0	1 - 3	2.2	1 - 2	1.2	1 - 3	1.4	1	1.0	1 - 2	1.4	1 - 2	1.3

[1] Based on analysis of 10 specimens of each sex whenever possible. The analysis of less than 10 specimens occurred frequently during the summer months when the number of indeterminates was higher.

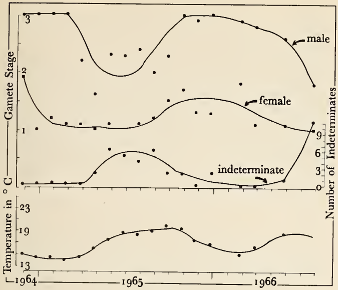

Figure 2

The seasonal variation in the average stage of male and female gamete development, the number of indeterminates, and water temperature at Station 1

SEASONAL VARIATION in FEMALE GAMETOGENESIS

Mature ova were present in some of the specimens in only 12 of the 68 samples analyzed and 6 of these were from Station 3 (Table 1). These mature ova were observed during some of the months between November and March except one instance in September 1965 at Station 4 and one in May 1966 at Station 4. A seasonal variation in the average stage of gamete development was noted at all stations during the 20-month observational period. While a considerable variation occurred from station to station, especially regarding the extent of the period of higher averages, the average stage of female gamete development was highest from November through February and lowest from about March through September (Figures 2 to 5).

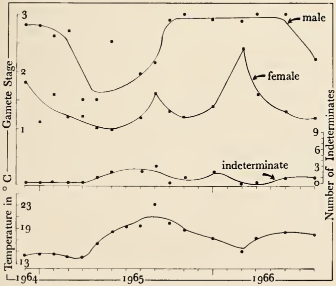

Figure 3

The seasonal variation in the average stage of male and female gamete development, the number of indeterminates, and water temperature at Station 2

Of the 68 samples analyzed for the stage of female gamete development 12 (or 18%) had specimens only in stage 1 or the follicle stage. Stage 1 was always observed in some of the specimens in a sample except at Station 2 in February 1966. The overall stage of female gamete development was 1.2, 1.4, 1.5, and 1.2 for stations 1 to 4, respectively. The length of time during which the average gamete stage of development was highest (over 1.7) was longer at Station 3 and shortest at Station 4.

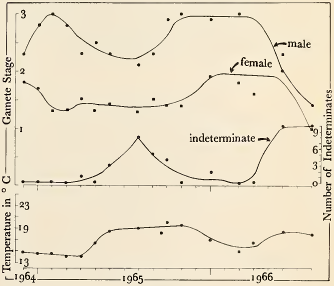

Figure 4

The seasonal variation in the average stage of male and female gamete development, the number of indeterminates, and water temperature at Station 3

NUMBER of INDETERMINATE INDIVIDUALS

The fluctuation in the number of indeterminates observed correlated inversely with the seasonal aspect of male and female gamete development. The number of indeterminates increased between April and August when the average level of gamete development was decreasing. The total number of indeterminates observed during the study was 31, 13, 43, and 36 at Stations 1 to 4, respectively.

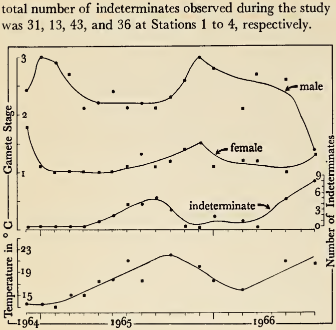

Figure 5

The seasonal variation in the average stage of male and female gamete development, the number of indeterminates, and water temperature at Station 4

DISCUSSION

The occurrence of mature gametes in *Mytilus edulis* reached a peak at all stations in the fall and early winter months in Alamitos Bay when the water temperatures decreased from 20° to 21° C in September to 15° C in December. Some stages of gametogenesis were observed in both sexes at all stations during the period of 20 months. More advanced stages were observed for longer periods of time in males than in females (Figures 2 to 5). These observations were similar to those reported by Sugiura (1959) for *M. edulis* in Japanese waters. Sexually mature mussels were abundant in October and November when the water temperature was 18° C and least abundant during August when temperatures reached 28½° C. Both of these observations are different to what was observed by Chipperfield (1953) in colder British waters. Gametes matured when the water temperatures rose above 7° C and spawning occurred from 2 to 6 weeks from mid-April through May when temperatures rose from 9½° to 12½° C. After spawning, Chipperfield noted a period of 2 to 3 months when all mussels were indeterminate.

Apparently, in the colder British waters the development of gametes and spawning are limited by water temperatures to a greater extent than in the more temperate waters of Japan and southern California. The period of time in which mature gametes are present is considerably longer in Japanese and southern California waters. Recovery from spawning with the subsequent redevelopment of the next generation of gametes occurs faster in the Japanese and southern Californian populations of *Mytilus edulis*. Longer reproductive seasons were found in the sea urchin *Strongylocentrotus purpuratus* (Stimpson) which were collected from warmer waters of lower latitudes than from colder waters of higher latitudes (Boolootian & Giese, 1959).

Gonad analyses could not be made from specimens of *Mytilus edulis* collected at the extremes of its distribution within Alamitos Bay because of insufficient numbers being present. Some differences, indicated by trends, have been noted at Stations 1 to 4. The overall average stage of male gamete development was slightly higher at Station 1 than at Station 4 with the other 2 stations intermediate. The period of time during which motile sperm are found is longer at Stations 1 and 2 than at Stations 3 and 4 (Figures 2 to 5). Variations in the average stage of female gamete development were observed but not at the same stations as for male gametes. The highest overall averages were noted at Stations 2 and 3 and the lowest at Stations 1 and 4.

It is apparent from these data that the propagation of *Mytilus edulis* in Alamitos Bay is dependent upon the presence of mature ova. Some males with mature, motile sperm were observed throughout the year, but mature ova were observed only during the late fall and winter months when water temperatures were at their lowest level (13° to 15° C). The maturation of male gametes does not seem to be affected by the range of water temperatures in Alamitos Bay as it is in British waters (Chipperfield, 1953): however, the maturation of the ova apparently is influenced by temperature in Alamitos Bay. The presence of motile sperm for a longer period of time than mature ova may be the result of: (1) not all sperm from a mussel are discharged at any one time, (2) additional sperm are produced rapidly and many times a year following a complete spawning, or (3) a combination of these. The shorter period of time in which mature ova are present may be the result of: ova are spawned from one mussel at one time and additional ova mature slowly and are produced only once a year.

The period of settlement of *Mytilus edulis* on boat floats in Alamitos Bay in the late winter to early spring months substantiates these observations of a late fall to winter spawning season. The length of larval life is unknown for these waters, but CHIPPERFIELD (*op. cit.*) calculated it to be about 4 weeks.

As noted above, there are indications that some ecological variations in the average stage of gamete development occurs in Alamitos Bay. It would be of interest to study this variation in a body of water where the population of mussels is sufficient in the environmental extremes. Secondly, *Mytilus edulis* would be a convenient organism with which to work in order to study the relationship of temperature, as a function of latitude, to the length of the reproductive period.

SUMMARY

1. Gonadal smears of the bay mussel *Mytilus edulis* were made at 4 stations at monthly intervals for 20 months in Alamitos Bay, Long Beach, California, to ascertain whether or not seasonal variation in gamete maturity exists.
2. Some degree of gametogenesis occurred throughout the period of observation. Mature sperm were present in some mussels throughout the year, but mature ova were present only from November through May. The number of indeterminate individuals varied directly with the water temperature.
3. Some slight variations were noted in the average stage of gamete development with both sexes collected from the different stations.

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